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CURRENT LITERATURE

BOOK REVIEWS

Senescence and rejuvenescence

Professor CHILD¹ has made a most thoughtful attempt to solve a fundamental biological problem; for the book contains not only an explanation of the phenomenon of growing old, or senescence, a process of much human interest, but it also contains the foundation of an even more important theory of an entirely novel kind on the problem of animal forms, regeneration and inheritance. The great value of the book is due not only to these philosophical and illuminating explanations, but also to the very large amount of original, experimental observations recorded in it. The author, as is well known, has been engaged for many years in the experimental study of the general problems of regeneration and morphogenesis in animals; in this treatise he presents not only the more important of the observations he has made but also the general conclusions to which this work has led. The book is full of material of fact, presented in a logical and convincing manner, to support the general theory of the nature of the process of senescence, the nature and extent of rejuvenescence, the significance of sexual reproduction and maturation, and the nature of the processes at work in the phenomena of regeneration, growth, and the determination of form in animals and plants. It thus contains the basis of a new theory of animal and plant forms, and a resulting new theory of the process of inheritance which is to be the subject of a separate treatise, shortly to appear. Not the least valuable feature of the book is that it treats of these general processes as they occur both in plants and animals, and the essential identity of the processes in the two living kingdoms is clearly revealed. Zoology and botany thus mutually illuminate each other, and the conclusions must arouse the keenest interest of both zoologists and botanists. The theories are so far reaching and fundamental that if substantiated they will profoundly alter many prevalent conceptions of biology. The book represents, therefore, one of the most original and important constructive contributions made by an American biologist.

The thesis of the author is that senescence is a universal attribute of living organisms, plants as well as animals. Where it appears to be absent, as in the infusoria and some plants, this is not due to its actual absence, but to a rejuvenescence taking place in more or less irregular rhythms by which the results of

¹ CHILD, C. M., *Senescence and rejuvenescence*. 8vo. pp. 481. University of Chicago Press. 1915. \$4.00.

senescence are overcome and the animal or plant returned to its youthful state. This process of rejuvenescence is not limited to lower forms of animals and to the plants, but occurs also, to some degree, in the higher animals as well, and even in man a limited rejuvenescence, at least in some tissues, is possible. One sees the process of senescence everywhere in living nature and it appears under various guises. Thus in the higher forms, and indeed in all forms, the process of sexual or gametic reproduction and the life cycle are in reality nothing but expressions of processes of senescence and rejuvenescence. The sex cells are senescent cells, which by uniting with each other accomplish their rejuvenescence and form a new, young individual. This conception is in sharp contrast with the current WEISMANN-GALTON view of a perennially young germ plasm, separate from the soma. Instead of the germ plasm being young and retaining its constitution unchanged in the soma, as such a theory requires, the germ cells are the most highly differentiated and oldest cells of the body, and they grow old in their development, just as the soma grows old. They are indeed parts of the soma, and the influence of the environment on these cells is just as pronounced as upon the soma cells, and there is no theoretical objection to the inheritance of acquired characters.

The first chapter of Part I is an especially clear and readable statement of the various theories of the constitution of the organism, and the author points out that the neo-vitalistic theory of the present day is a logical outcome of the corpuscular theories of inheritance.

"An orderly progressive development of a definite character is inconceivable in an organism composed of a very large number of independent ultimate units, each capable of growth and reproduction, except under the influence of some controlling and directing principle, entelechy, distinct from the ultimate units themselves. If such theories represent the last word of science concerning the physico-chemical constitution of the organism, then we must all be vitalists, whether we admit it or not."

The corpuscular theories necessitate an entelechy to arrange the corpuscles, as DRIESCH and others have seen. It is the corpuscular theory of living matter which is attacked in the book from cover to cover. There are taken up in turn in this chapter, the corpuscular, the chemical, and finally the physico-chemical theory of life phenomena, based on the colloidal substratum of living matter. Of the last theory a particularly clear account is given, and the organism compared most happily to a river.

"Neither water alone nor the banks and the bed alone constitute the system which we call a river; and in nature the banks, the bed, and the current have been associated from the beginning. Here, also, structure and function are connected as in the organism: the configuration of the channel modifies the intensity and course of the current, and the current in turn modifies the morphology of the channel by deposition at one point, giving rise to structures such as bars, islands, flats, and by erosion at another."

Just so in the organism the metabolic stream raises bars and dams of sediment, and the current is thereby turned aside, or it may be narrowed and deep-

ened. The essential cause of senescence is this deposit of colloidal material in the bed of the living stream, a deposit which becomes optically visible in the progressive differentiation of the protoplasm. This simple principle of the guiding of the living stream by its erosions and sediments is at the bottom not only a senescence and differentiation of cell protoplasm, but of all that differentiation of the organism in embryonic development, which results finally, as the living stream flows on, in the considerable chemical differences between different organs and in the gradual and necessary aging of the individual. Thus from a very simple germ a very complex organism is evolved, and quantitative, not qualitative, differences in rate of metabolism produce eventually a differentiation in kind of metabolism.

The work is the outcome of the discovery of a particularly favorable material for the study of the problem of senescence and rejuvenescence, together with the discovery of a method of testing the degree of aging or youth. The material discovered is the flatworm *Planaria* and related species. These animals often do not reproduce sexually, but detach a part of the body which undergoes dedifferentiation and rejuvenescence to a young animal. Such pieces emerge from encystment young animals. In them, therefore, there is a regular series of senescences and rejuvenescences taking place in a brief time, and experiments may be tried on the control of the process to determine its nature. From these forms one can interpret the similar phenomena shown by other organisms. The method of study consists in the discovery of several simple ways of determining the degree of youth, or, in other words, the degree of metabolism, for the metabolism of the young is keener than that of the old. One method is by the use of potassium cyanide. The susceptibility to this poison is a direct measure of the speed of metabolism, if animals of the same kind but different ages are compared. In addition to potassium cyanide the susceptibility to anesthetics, or the power of acclimatizing to very weak doses of anesthetics such as alcohol, also furnishes a criterion of youth or age, or rather of youthful metabolism. These methods have been controlled by the direct measurement of the amount of carbon dioxide exhaled per gram of tissue as determined by TASHIRO in his biometer, and these measurements have completely confirmed the observations on the cyanides. By observing the animals in cyanide solutions, it is found that the parts of the animal which have the higher rate of metabolism die first, the death changes being very clear and easily perceived. It became possible thus to study the rate of metabolism in different parts of the animal and under various conditions of age, temperature, after injury, etc., and a large number of very striking and instructive experiments on many different forms have been recorded. Chapters 3, 4, 5, and 6 of Part II deal with the method, with the phenomena of the susceptibility to cyanide, and the rate of metabolism occurring in the reconstitution of new organisms from pieces of *Planaria*, whether these pieces are sexual cells, or cysts, or pieces cut from the adult worm. The process of reconstitution of the animal form is always a process of rejuvenescence, of a dedifferentiation, and the restoration

of youthful, in the place of old, protoplasm. However, the new animal is produced, it is found to become young, in its metabolism, as if it came from an egg. Chapter 6 shows that this same process occurs also in agamic reproduction in other forms, such as certain annelids, in protozoa, coelenterates, etc.

Chapter 7 deals with the artificial control of rejuvenescence apart from reproduction. It is found possible by starving in these animals to bring about dedifferentiation and complete rejuvenescence. By starvation the obstacles to metabolism are removed and the metabolic rate rises to just the same degree as it does in a young individual formed by sexual reproduction.

In Part III is recorded a very fundamental discovery which has been made the basis of the author's explanation of the attainment of animal forms and the development of a highly elaborated adult from a simple germ, without assuming that the germ has almost as complex a character as the adult, due to the number of units or pangenes in it. This fundamental discovery is that of the axial gradient of metabolism, and the dominance and subordination of parts during development in relation to this gradient. The author had found that the head end of an animal, or that part where the nervous system lies, or is to lie, has a higher rate of metabolism than the parts lying behind it. There is in the body of *Planaria*, and in other animals as well, a metabolic gradient from before backward, and from the midline toward the sides, and sometimes from back to belly. These are three coordinate axes. The parts which are most active metabolically exercise an inhibitory power on the less active parts in a manner exactly analogous to the control exercised by the growing tip of a plant on the older parts. It is this control of the more rapidly metabolizing parts which controls the development, and differentiation, and dedifferentiation. This conclusion is proved by experiments showing that if in any way the control of the dominant region is removed, the subordinate parts may attain to dominance in their turn and start a new head, and by a resulting reorganization of the materials cause the appearance of a new individual. The development of any part of the growing organism is determined by the position the part occupies in its relation to these coordinate axes of metabolic gradients. If, for example, one removes the head, the parts behind it are now released from the inhibition exercised by a more rapid metabolism in front of them, the rate of the anterior margin at once rises and dominates the parts behind, the material is reorganized from this new head and a new individual produced. This discovery, which is established by a very large amount of experimental observations, enables one to control the processes of regeneration and morphogenesis. It explains a vast number of facts of regeneration morphogenesis, teratomas, and so forth, for which there has been hitherto no explanation at all. It is brought into this book because, with the release of metabolic control of anterior regions, rejuvenescence occurs, and dedifferentiation. Animals thus show themselves to be in essentials, so far as their morphogenesis is concerned, like plants, in which the dominance of the growing tip has

long been recognized. The nature of the control is not specified, but it is suggested that it is in the nature of nerve impulses.

In this part, also, is considered senescence in the higher forms, in man himself, and the various changes in the tissues are pointed out. Various theories are criticized and the evidence examined, showing that here, also, the accumulation of colloidal material in some of the cells is probably the cause of senescence. By fasting a limited degree of rejuvenescence is possible. Various theories of the cause of the length of life are examined.

Part IV brings the sexual or gametic reproduction of animals and plants into the discussion. A great number of cases are examined, particularly in plants, where the conditions are especially illuminating. The phenomena of the conjugation of the gametes is interpreted from the same point of view. The gametes are highly differentiated cells; they are, therefore, old cells, and are among the most senescent in the body. In this the author agrees with MINOT. By conjugation, rejuvenescence is produced and a young individual formed. The fact of this rejuvenescence is demonstrated by the study of the rate of metabolism of quite a number of larvae and embryos at various stages of their life history; and the progressive rejuvenescence is followed not only by the change in structure of the protoplasm but by the increasing rate of metabolism; and the point where the tide turns and senescence begins is noted.

Part V is theoretical and critical, and in this the conception that senescence is due to any relation of the amount of nuclear to cytoplasmic matter, or that growth is an autocatalysis, is criticized adversely. Finally, the problem is raised whether there is not also a progressive senescence in the protoplasm as a whole, a growing old of races as well as individuals, and whether this is not the cause of the progressive evolution of living things. A few quotations will make clear the author's standpoint and also illustrate the interesting and thoughtful style of the book.

"Physiological or natural death is not something which has originated in the course of evolution from the lower to the higher forms. All organisms, from the lowest to the highest, from the simplest to the most complex, undoubtedly die of old age, unless senescence is compensated by rejuvenescence. In the lower forms the death point may never be attained under the usual conditions, because the low stability of the substratum and the consequent degree of individuation permit the frequent occurrence of a high degree of rejuvenescence. In the higher forms death becomes inevitable and necessary because the capacity for rejuvenescence is limited by the greater stability of the substratum. For his high degree of individuation man pays the penalty of individual death, and the conditions and processes in the human organism which lead to death in the end are the conditions and processes which make man what he is. The advance of knowledge and of experimental technique may make it possible at some future time to bring about a greater degree of rejuvenescence and retardation of senescence in man than is now possible, but when we remember that the present condition of the protoplasmic substratum of these organisms is the result

of millions of years of evolutionary equilibration, we cannot but admit that this task may prove to be one of considerable difficulty."

"Senescence and rejuvenescence do not include special processes, they are merely certain aspects of the relations between the metabolic reactions and the protoplasmic substratum. Senescence means the greater stability of this substratum; rejuvenescence, its greater instability."

"Moreover, the course of development of the gametes bears every indication of being a progressive differentiation and senescence, not fundamentally different from that of other organs of the body, and the fully developed gametes are physiologically old, highly differentiated cells which are rapidly approaching death and in most cases actually do die soon after maturity, unless fertilization occurs. These cells must be dedifferentiated or undergo rejuvenescence before they can enter on a new period of development. In the plants this may occur to a greater or less extent without fertilization in the development of the gametophyte, but in the gametes of animals, with the exception of parthenogenetic eggs, dedifferentiation and rejuvenescence occur only after fertilization."

"From this point of view gametic reproduction differs from agamic only in the greater degree of specialization of the reproductive cells and the special conditions necessary to initiate the process of dedifferentiation and rejuvenescence. The same periodic changes, the same life cycle and age cycle occur in both. We can dispense entirely with that remarkable conception, the germ plasm of the WEISMANN theory, and say that germ plasm is any protoplasm capable under the proper conditions of undergoing dedifferentiation and reconstitution into a new individual of the species."

Physiologists should be particularly interested in this theory. For the first time we have an explanation of the processes of morphogenesis which is essentially physiological, and which may be tested by physiological methods. The control of the growing tip, or the rapidly metabolizing head end of the animal, is supposed to be exerted on the parts less active by means of something of the nature of nerve impulses spreading from one region to the other. This conception will undoubtedly appeal to the majority of physiologists. Similarly, for the first time we have at least the foundation of a physiological explanation of the manner in which, from a simple germ, a highly differentiated adult will and must arise. The morphological conception of pangenesis is entirely abandoned. The book is thus essentially constructive, and not a destructive criticism only of such views. To the pharmacologist the discovery of the cause of the sensitivity of the nervous system to drugs of all kinds and its relation to metabolism is a matter of very great interest and importance. To the ordinary man of a philosophical temperament this book must appeal for its solid thoughtfulness, clear exposition, and cautious conclusions. The large number of well executed illustrations greatly adds to the ease of following the text. Zoologists and botanists have here a theory which offers an explanation of the most interesting and obscure of their phenomena. It presents a possible and apparently a practicable means of escape from neo-vitalism.—A. P. MATHEWS.